High-Resolution Simulations of the Formation of Potentially Habitable Planets

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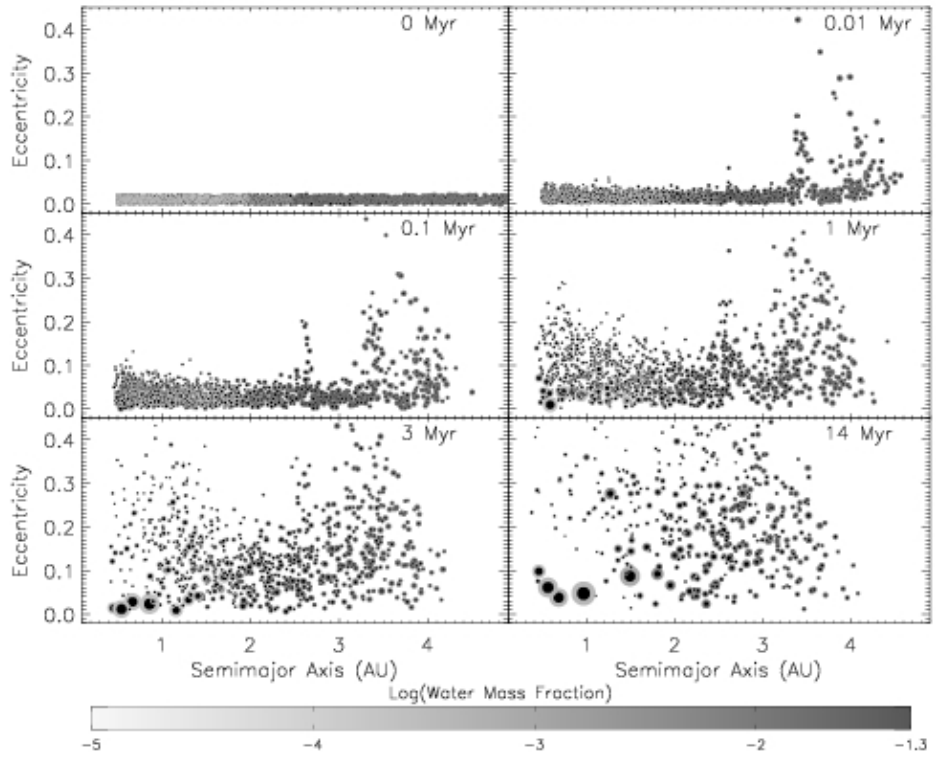
The orbital eccentricities of terrestrial planets formed in most simulations to date are much higher than the values for Venus, Earth, and Mars in our Solar System. We attempt to solve this problem by simulating the formation of potentially habitable, terrestrial planets with unprecedented resolution. A simulation begins with a disk of protoplanets and an already-formed gas giant. The orbits of all bodies are evolved for 200 million years while tracking their water and iron contents, which may change via collisions with objects of different compositions. We use both an existing serial code ("Mercury") and a new parallel code ("pkdgrav") to perform the calculations, with 1000-2000 initial particles, five to ten times more than in most previous simulations.

The eccentricities of the terrestrial planets we form are indeed smaller, largely due to the dissipative effects of small bodies and an increased collision rate. Planets of substantial mass form in the Habitable Zone, and accrete water-rich material from past the snow line, although many more impacts are required to deliver an Earth ocean than in previous simulations. Most such accretion events occur late in the formation process, when planets inside 1.5 AU have reached a substantial fraction of their final mass.

The figure below shows six snapshots in the evolution of one simulation with 2000 initial particles. Note that the simulation has not completed, and extends only to 14 million years.


0 Myr
0.01 Myr
0.1 Myr
1 Myr
3 Myr
14 Myr
Eccentricity
0.0
0.1
0.2
0.3
0.4
1
2
3
4
Semimajor Axis (AU)
Log(Water Mass Fraction)
−5
−4
−3
−2
−1.3